LEVEL II AD-

NWC TP 6275

12

AD A103198

Survivability of Penetrators With Circumferential Shear-Control Grooves

by

J. C. Schulz

and

O. E. R. Heimdahl

Research Department

April 1981

NAVAL WEAPONS CENTER

CHINA LAKE, CALIFORNIA 93555

Approved for public release; distribution unlimited.

Naval Weapons Center
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

FOREWORD

The research described in this report was conducted in support of controlled fragmentation studies for hard target penetrator warheads under the Air Strike Warfare Weaponry Technology Block Program at the Naval Weapons Center. The work was performed during Fiscal Year 1981, and was funded by AIRTASK WF32395, Program Element 62332N, Work Unit 1321051.

This report was reviewed for technical accuracy by John Pearson.

Approved by
E. B. ROYCE, *Head*
Research Department
1 April 1981

Under authority of
W. B. HAFF
Capt., U.S. Navy

Released for publication by
R. M. HILLYER
Technical Director

NWC Technical Publication 6275

Published by..........................Technical Information Department
Collation...Cover, 15 leaves
First printing.....................................155 unnumbered copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NWC TP 6275	2. GOVT ACCESSION NO. AD-A103	3. RECIPIENT'S CATALOG NUMBER 198
4. TITLE (and Subtitle) SURVIVABILITY OF PENETRATORS WITH CIRCUMFERENTIAL SHEAR-CONTROL GROOVES		5. TYPE OF REPORT & PERIOD COVERED Research Report Fiscal Year 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. C. Schulz and O. E. R. Heimdahl		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AIRTASK WF32395, 62332N 1321051
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		12. REPORT DATE April 1981
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Survivability
Cylinders
Penetrators
Shear-control
Warheads
Small-scale firings

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102 LF 014 6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(U) *Survivability of Penetrators With Circumferential Shear-Control Grooves*, by J. C. Schulz and O. E. R. Heimdahl. China Lake, Calif., Naval Weapons Center, April 1981. 28 pp. (NWC TP 6275, publication UNCLASSIFIED.)

(U) Small, cylindrical, steel projectiles containing circumferential grooves were fired against simulated concrete and steel-plate targets to investigate possible effects of shear-control grid placement on the survivability of impacting warheads. The projectiles fired against simulated concrete developed a bulge near the front of the internal cavity. The presence of a groove in this region significantly reduced the breakup velocity, while a groove a short distance to the rear had no effect on survivability. Thus, a shear-control grid could be machined from slightly behind the bulge to the rear of a warhead case without reducing survivability while, at the same time, maintaining a significant amount of fragmentation control. Against steel-plate targets, damage to the projectile was confined primarily to the front end, and a groove in the internal cavity, whether at the bulge location or behind it, had little effect on structural survivability.

A

CONTENTS

INTRODUCTION

The shear-control method of warhead fragmentation, as described by Pearson,[1,2] has been employed in a variety of bombs and warheads to produce fragments of pre-determined size and shape. Typically, a diamond-shaped grid is either machined or formed into the inside surface of a warhead case. The grid is composed of families of left- and right-hand spiral grooves, which act as stress raisers such that the fragmentation process is governed by the initiation of shear fractures at the root of the grid elements. The size and shape of the fragments produced is controlled by the design parameters of the particular grid.

For warheads required to survive penetration or perforation of targets prior to detonation, these stress-raising grooves may have the unwanted effect of inducing premature structural failure of tne warhead case. It has been hypothesized that should such failure occur, it would be primarily due to the presence of grooves in the highly stressed region near the front of the explosive cavity where a bulge often develops in the warhead case at the transition location between nose and wall. Thus, failure might be avoided by the expedient of not extending the grid forward into this region. The effect of shear-control grids on warhead survivability has not been extensively investigated.

This report describes the results of a series of firings of small, cylindrical, steel projectiles containing circumferential grooves against simulated concrete and steel-plate targets. The grooves were located either at the point of maximum bulging near the front of the projectile cavity or a short distance to the rear of this point. In addition, some ungrooved projectiles were fired for comparison purposes. Similar firings of ungrooved projectiles only have been reported by Stronge and Schulz.[3] The purpose of the current firings was to test the above hypothesis

---

[1] John Pearson. "The Shear-Control Method of Warhead Fragmentation," in *Proceedings of the Fourth International Symposium on Ballistics, Monterey, California, 17-19 October 1978*. Monterey, Calif., Naval Postgraduate School, 1978. Publication UNCLASSIFIED.

[2] Naval Weapons Center. *Parametric Studies for Fragmentation Warheads*, by John Pearson. China Lake, Calif., NWC, April 1968. (NWC TM 4507, publication UNCLASSIFIED.)

[3] W. J. Stronge and J. C. Schulz. "Projectile Impact Damage Analysis," in *Proceedings of the Symposium on Computational Methods in Non-linear Structural and Solid Mechanics, Arlington, Virginia, 6-8 Oct. 1980*. Published as special issue of *J. Computers & Structures*, Vol. 13, No. 1-2, (1981), pp. 287-294.

regarding the influence of grid placement on warhead survivability, the grooves being intended to roughly simulate the effect of the shear-control grid. At the same time, the results are not restricted to shear-control grids only, but are applicable to other stress raisers in impacting projectiles. It is anticipated that additional results obtained through metallurgical examination of cross-sectioned projectiles will be covered in a later report.

DESCRIPTION OF EXPERIMENTS

PROJECTILES

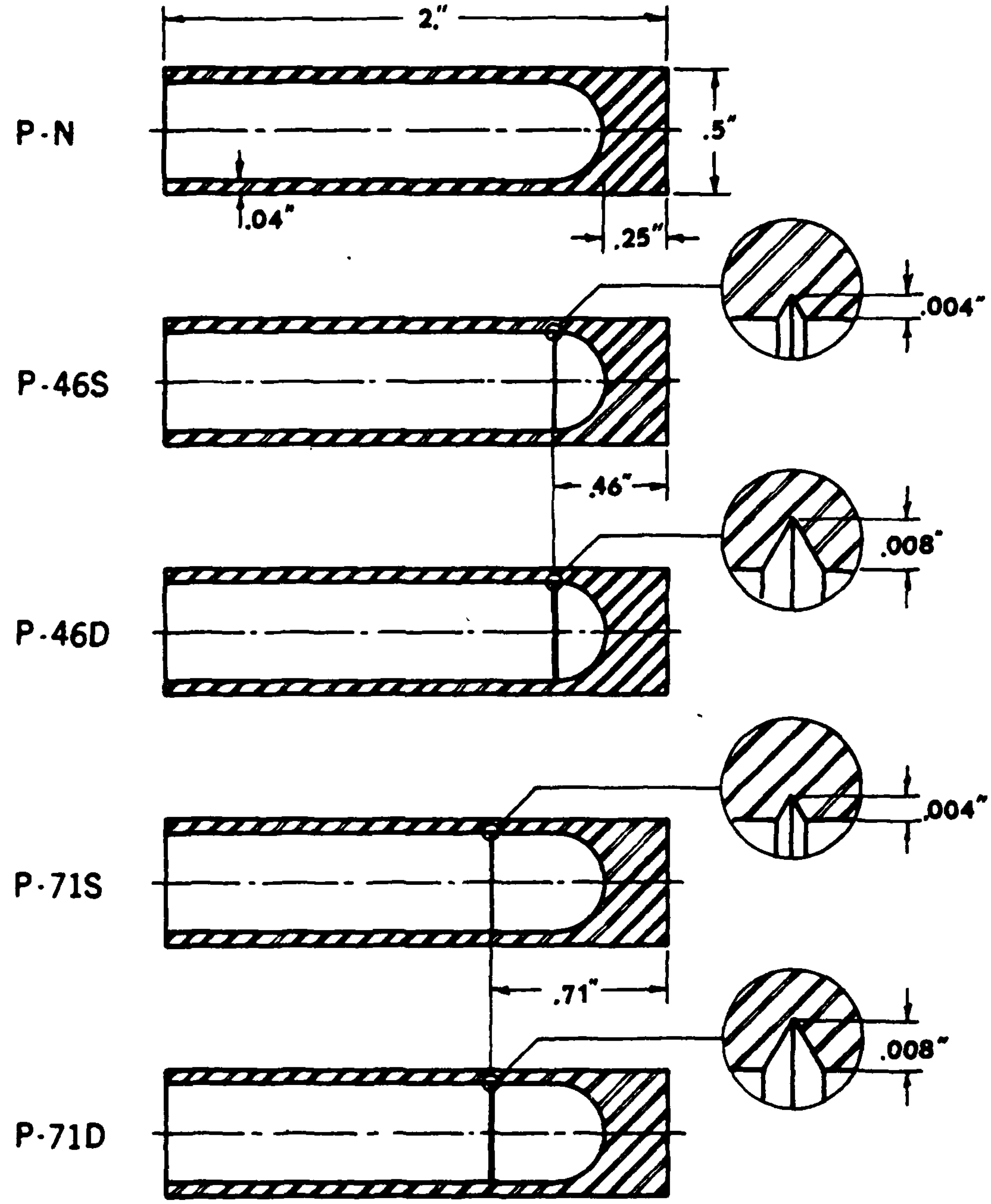
The projectiles were all flat-fronted, hollow cylinders, 2 inches long and 0.5-inch in diameter. The hemispherical front of the internal cavity was 0.25 inch from the front end of the projectile. The cavity wall was 0.04-inch thick. The grooves were located either 0.46 or 0.71 inch from the front end, and were either 0.004- or 0.008-inch deep. Thus, counting the ungrooved projectiles, there were altogether five different configurations. Cross-sectional views of the projectiles with details of the grooves are shown in Figure 1. Abbreviated designators for the projectiles are also given (P-N, P-46S, P-46D, P-71S, and P-71D, where N means no groove, 46 and 71 are groove distances from the front end in hundredths of an inch, and S and D indicate the shallower and deeper grooves, respectively). All of the projectiles were machined from 4340 steel rods and were heat-treated to a Rockwell C hardness of 38 to 40.

TARGETS

The projectiles were fired against two different targets: simulated concrete and steel plate.

Simulated concrete targets were made of Thorite (® Standard Dry Wall Products), a fast-setting, high-strength (3950 psi compressive strength) concrete patching compound consisting of sand, cement, and additives to promote rapid curing. The largest sand grains are about 0.04 inch in diameter. The targets were cured for 7 days prior to the firings. The targets were wet-cured (with their surfaces covered with water) for 24 hours and allowed to dry-cure (with their surfaces exposed to air) for the remaining 6 days. It was found that care in preparation of the targets was required to ensure high strength and uniformity. The preparation procedure used is described in Appendix A.

Steel-plate targets were cut from 1/16th-inch-thick sheets of a hot-rolled, low-carbon steel with a Rockwell B hardness of 55.



MATERIAL: 4340 STEEL, R_c 38-40

FIGURE 1. Cross-Sectional Views of Test Projectiles With Details of Grooves.

EXPERIMENTAL PROCEDURE

The projectiles were fired from a smooth-bore, 50-caliber powder gun. Impact velocities were measured in the gun barrel with a photo diode system coupled to an interval counter. The Thorite targets were placed about 18 inches from the end of the barrel, and the steel-plate targets about 6 inches from the end of the barrel. The projectiles impacted the targets at normal obliquity. Projectiles that perforated steel-plate targets were captured in a recovery trough filled with Celotex® slabs placed immediately behind the targets. The apparatus is described more fully by Goldsmith and Finnegan.[4]

RESULTS AGAINST THORITE TARGETS

Thirty shots were fired against Thorite targets. The results are summarized in Table 1. Photographs of all the projectiles after test are contained in Figure B-1 in Appendix B. Photographs of selected cross-sectioned projectiles are shown in Figure B-2.

During penetration, high stresses generated near the front of the internal cavity result in considerable plastic deformation and the development of a bulge near the junction between hemisphere and side wall (Figure B-1, P-N, 2490 fps, for example). At sufficiently high impact velocities, a circumferential fracture occurs in the bulged region, resulting in separation of the front portion from the rear portion (Figure B-1, P-N, 2515 fps). In some cases, the front portion, although separate from the rear portion, was displaced backwards into the rear portion and the two were recovered as one piece (Figure B-1, P-46S, 2480 fps). The fracturing of the rear portion into long, thin petals reported by Stronge and Schulz for a slightly different projectile geometry[3] did not occur.

The presence of a circumferential groove at the front of the internal cavity (in the P-46S and P-46D projectiles) did not make a noticeable difference in the appearance of the primary bulge at this location (although it did have a significant effect on the survival velocity of the projectile, as will be discussed). The presence of a groove 0.25 inch to the rear (in the P-71S and P-71D projectiles) resulted in a secondary bulge at this location. This secondary bulge is due to dynamic yielding along two 45-degree trajectories emanating from the tip of the groove which results in a wedge-shaped ring of material being displaced

---

[4] W. Goldsmith and S. A. Finnegan. "Penetration and Perforation Processes in Metal Targets At and Above Ballistic Velocities," *Intl. J. Mech. Sci.*, Vol. 13 (1971), pp. 843-866.

TABLE 1. Results of Projectile Firings Against Thorite Targets.

Proj. type	Mass, gm	Impact velocity, fps	Penetration depth, in.	Front bulge diam., in.	Cavity bulge diam., in.	Dist. from front to cavity bulge, in.[a]	Length, in.	Description
P-N	20.05	2180	3.4	.512	.549	.47	1.958	Bulged
P-N	20.17	2390	3.1	.518	.594	.44	1.916	Bulged
P-N	19.97	2440	3.6	.519	.587	.44	1.925	Bulged
P-N	19.93	2480	3.4	.517	.602	.44	1.906	Bulged
P-N	20.00	2490	3.3	.517	.613	.42	1.892	Bulged
P-N	19.99	2515	2.9	....	....	...	....	Broke up
P-N	19.97	2520	2.8	....	....	...	....	Broke up
P-N	20.02	2520	3.0	....	....	...	....	Broke up
P-N	20.07	2525	2.9	....	....	...	....	Broke up
P-N	19.94	2555	2.8	....	....	...	....	Broke up
P-46S	19.96	2155	2.6	.512	.559	.45	1.952	Bulged
P-46S	19.92	2210	3.1	.512	.572	.45	1.938	Bulged
P-46S	20.09	2320	3.3	.514	.566	.44	1.950	Bulged
P-46S	19.83	2407	2.5	....	....	...	....	Broke up
P-46S	19.99	2480	3.0	....	....	...	....	Broke up
P-46D	19.81	2080	2.7	.511	.551	.45	1.961	Bulged
P-46D	19.85	2130	3.0	.508	.557	.44	1.961	Bulged
P-46D	19.88	2140	2.1	....	....	...	....	Broke up
P-46D	19.86	2190	2.1	....	....	...	....	Broke up
P-46D	19.87	2210	2.4	....	....	...	....	Broke up

See footnote at end of table.

TABLE 1. (Contd.)

Proj. type	Mass, gm	Impact velocity, fps	Penetration depth, in.	Front bulge diam., in.	Cavity bulge diam., in.	Dist. from front to cavity bulge, in.[a]	Length, in.	Description
P-71S	20.01	2460	3.2	.522	.619	.41	1.878	Bulged
P-71S	19.91	2475	2.4	....	....	...	....	Broke up
P-71S	20.00	2490	2.9	....	....	...	....	Broke up
P-71S	19.92	2535	2.9	....	....	...	....	Broke up
P-71S	19.97	2540	3.2	....	....	...	....	Broke up
P-71D	19.92	2350	3.1	.519	.580	.44	1.920	Bulged
P-71D	19.94	2435	3.1	.515	.619	.42	1.904	Bulged
P-71D	19.95	2448	3.1	.518	.587	.44	1.910	Bulged
P-71D	19.88	2490	3.2	....	....	...	....	Broke up
P-71D	19.91	2525	3.0	....	....	...	....	Broke up

[a] Measured after test.

outwards (Figure B-1, P-71D, 2448 fps). The deformation associated with the secondary bulge is minor compared to the primary bulge, and does not appear to contribute to failure of the projectile.

The chart in Figure 2 shows the impact behavior of the five types of projectiles within the velocity range studied. The solid vertical lines denote projectiles that bulged, while the dashed vertical lines denote projectiles that broke up. The greyed areas indicate a range of uncertainty for the survival velocity (defined as the velocity below which the projectiles bulge and above which they break up) for the different projectile types.

Estimated survival velocities are given in Table 2. The uncertainty indicated in the table is primarily due to the small number of shots fired and not to any inherent physical randomness in the targets, projectiles, or launch procedure. It is apparent from Table 2 that a groove at the point of maximum bulging significantly reduces the survival velocity and that the amount of reduction is strongly dependent on the depth of the groove (6% for the P-46S projectile and 15% for the P-46D projectile). On the other hand, a groove 0.25 inch to the rear of this point has almost no effect on the survival velocity for either groove depth (P-71S or P-71D).

TABLE 2. Projectile Survival Velocities
Against Thorite Targets.

Type	Survival velocity, fps	Uncertainty, fps
P-N	2502	±12
P-46S	2363	±43
P-46D	2135	±5
P-71S	2467	±7
P-71D	2469	±21

Penetration depth is plotted versus impact velocity in Figure 3. Also shown are theoretical curves based on the penetration theory of Bernard and Creighton[5] using Thorite property values given by Stronge and Schulz.[3] The curve labeled ".25" radius" is the theoretical penetration curve for a non-deforming projectile. As expected, this curve

---

[5] Defense Nuclear Agency. *Projectile Penetration in Earth Material: Theory and Computer Analysis*, by R. S. Bernard and D. C. Creighton. Washington, D.C., DNA, November 1977. (Contract Rept. S-76-13, publication UNCLASSIFIED.)

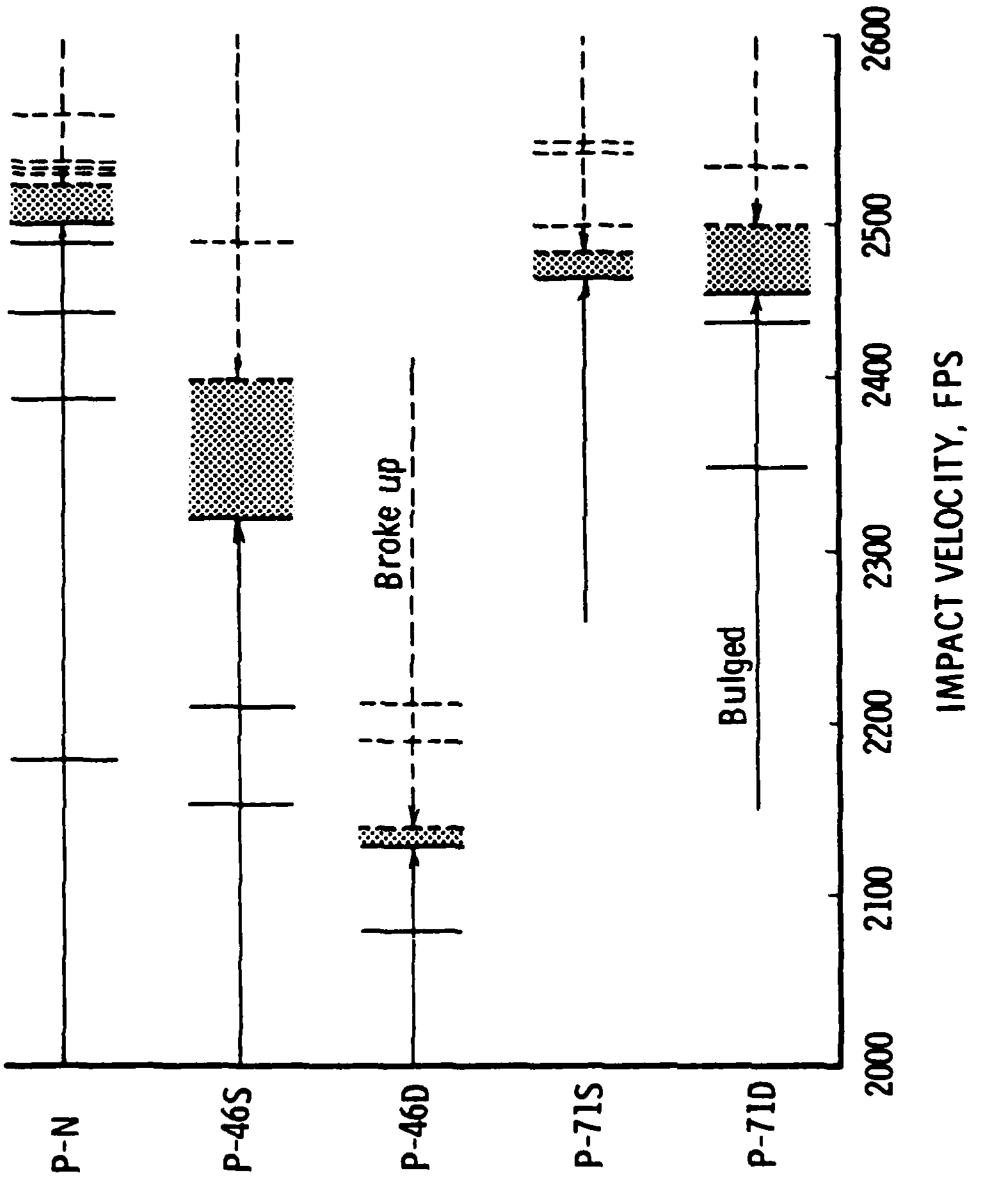


FIGURE 2. Impact Behavior of Projectiles Fired Against Thorite Targets.

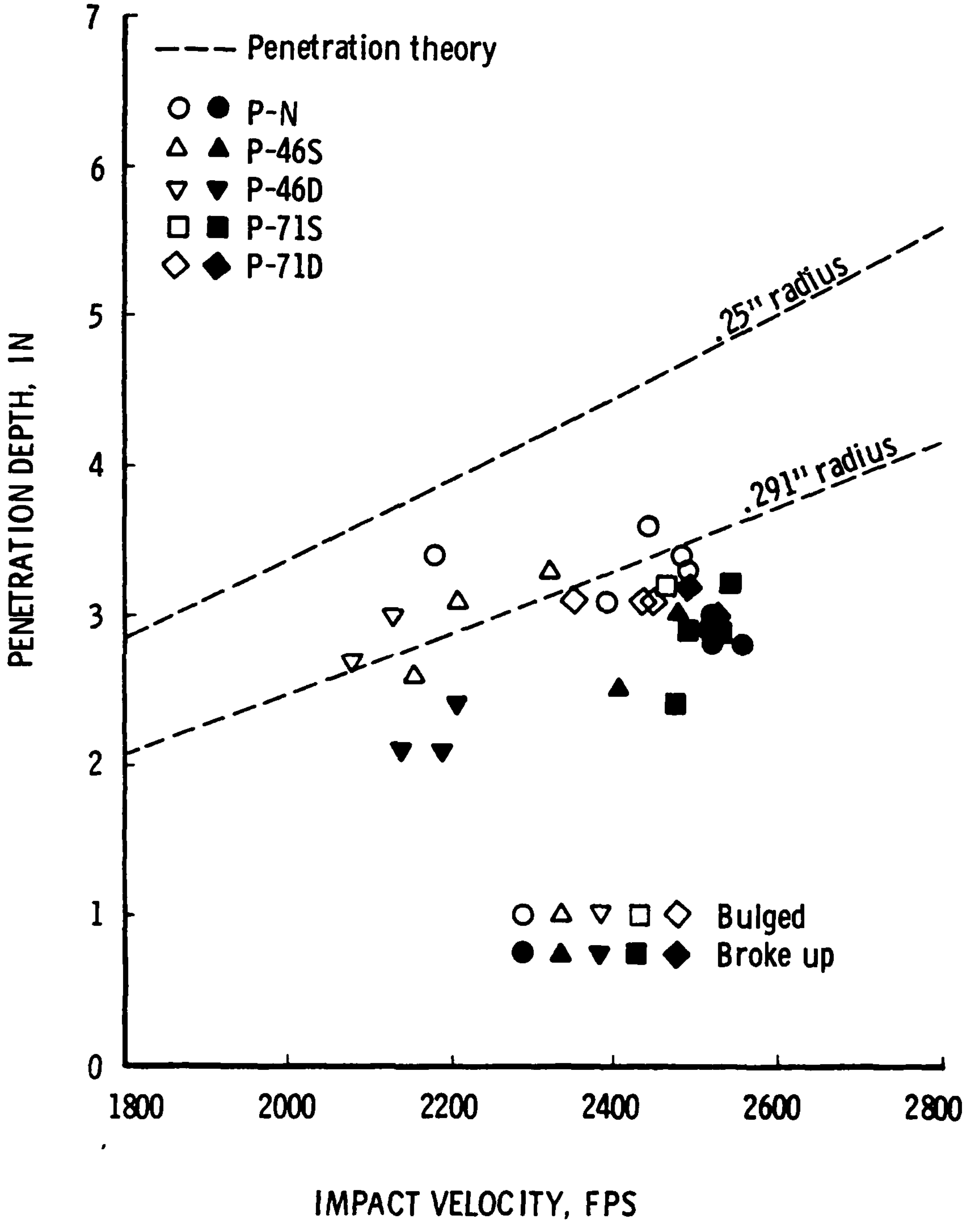


FIGURE 3. Penetration Depth Versus Impact Velocity for Test Projectiles Fired Against Thorite.

lies considerably above the experimental points. During penetration the radius of the projectile at the bulge increases significantly above its initial value, an increase not considered by Bernard and Creighton. If a fictitious radius of 0.291 inch (the average of the deformed cavity radii in Table 1) is used in the penetration theory, much better agreement is obtained. For a given impact velocity, the penetration depths of projectiles that broke up are considerably less than for those that did not break up. This can be attributed to a greater effective radius for the failed projectiles.

The decrease in projectile length, the height of the primary bulge in the internal cavity (the increase in radius at this location), and the increase in radius of the solid front end of the projectile are plotted versus impact velocity in Figures 4, 5, and 6, respectively. Also shown are theoretical lines obtained from finite element analysis analogous to that of Stronge and Schulz.[3] The analysis was for an ungrooved projectile. Reasonable agreement between analysis and experiment was obtained. In Figures 4 and 5 the experimental points for those projectiles with a groove at the cavity bulge (P-46S and P-46D) lie (with one exception) slightly above the theoretical lines, indicating that the presence of a groove at the cavity bulge results in more bulging and a greater decrease in length for a given impact velocity. This is consistent with the lower survival velocities found for these projectiles.

RESULTS AGAINST STEEL-PLATE TARGETS

Twenty-six shots were fired against steel-plate targets. The results are summarized in Table 3. Photographs of the projectiles after test are contained in Figure B-3 in Appendix B. Photographs of selected cross-sectioned projectiles are shown in Figure B-4.

Impact at lower velocity produced cracks on the front surface of the projectile (Figure B-3, P-N, 2480 fps, for example). The amount of cracking increased with increasing velocity, sometimes concentrating in a circular pattern (Figure B-3, P-N, 3230 fps). In some cases, perhaps due to slight non-normality of the impact, fracturing and breakup of the front end occured primarily on one side (Figure B-3, P-N, 2995 fps). At higher velocities, the steel disk punched from the target sometimes remained attached to the front of the projectile (Figure B-3, P-46S, 3275 fps).

Damage to projectiles fired against steel-plate targets was confined largely to the front end. Bulging occurred at the primary location at the front of the internal cavity, but was significantly less than for impact against Thorite. The presence of a groove at this location resulted in increased bulging and some alteration in the shape of the

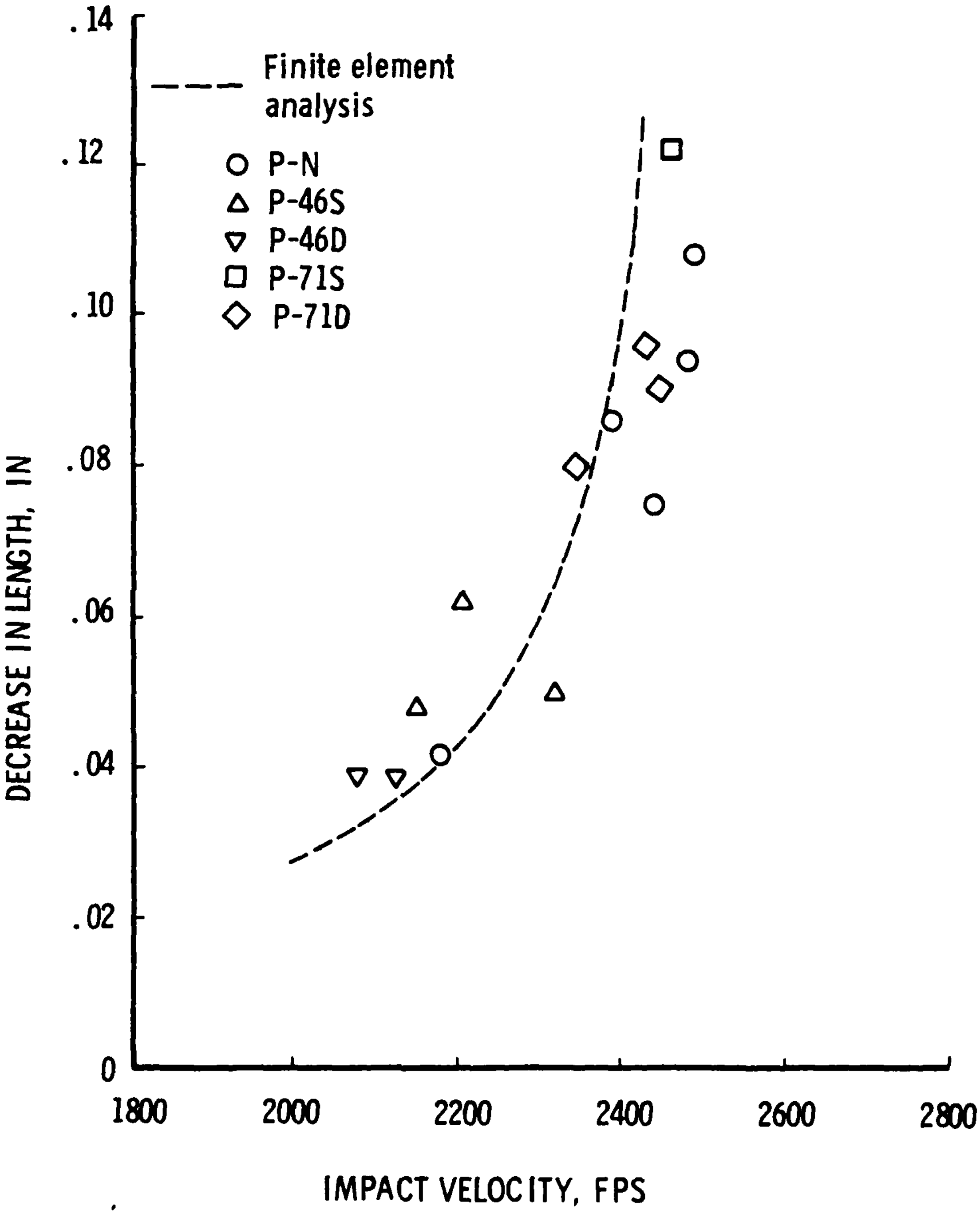


FIGURE 4. Decrease in Length Versus Impact Velocity for Test Projectiles Fired Against Thorite.

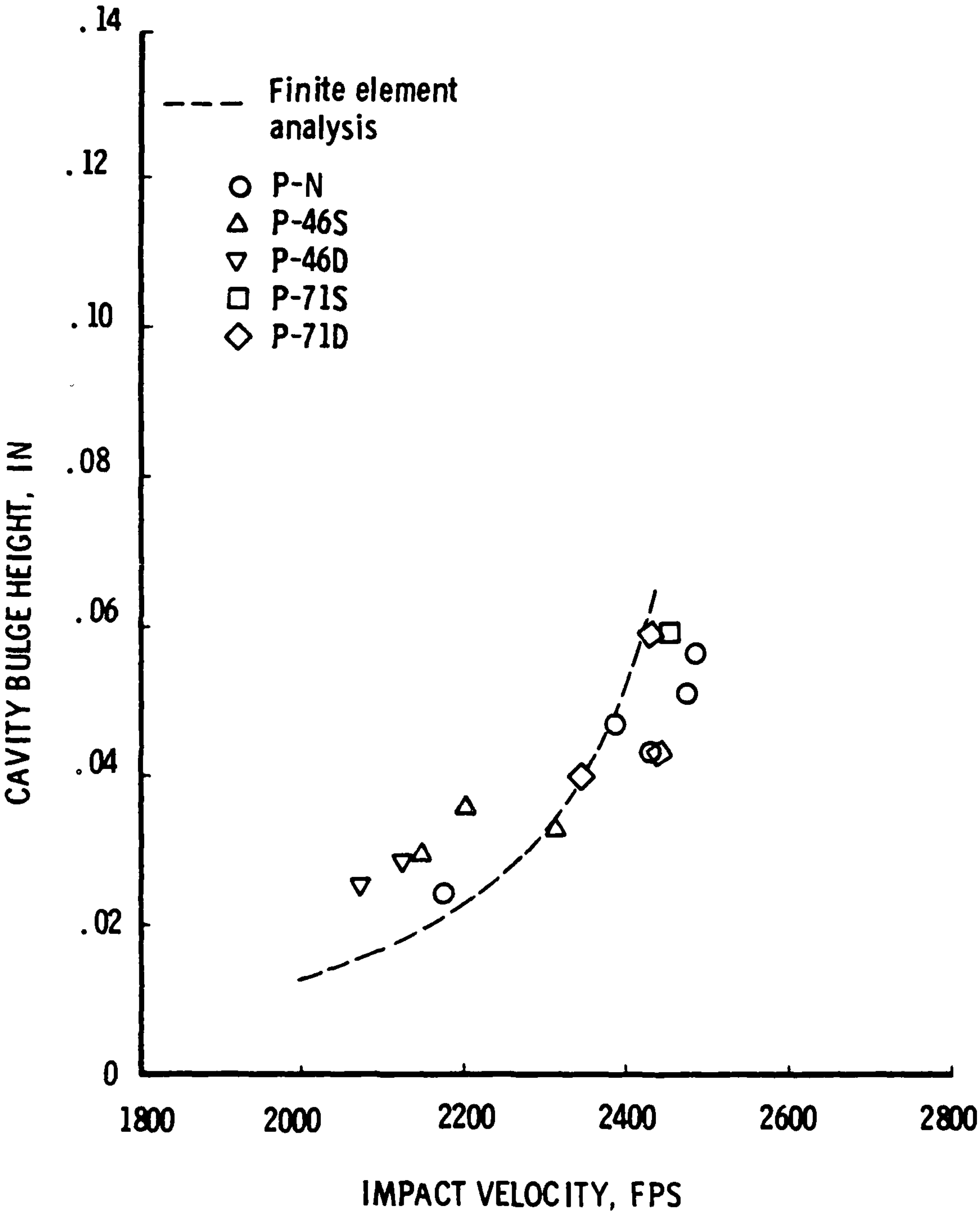


FIGURE 5. Cavity Bulge Height (Increase in Radius) Versus Impact Velocity for Test Projectiles Fired Against Thorite.

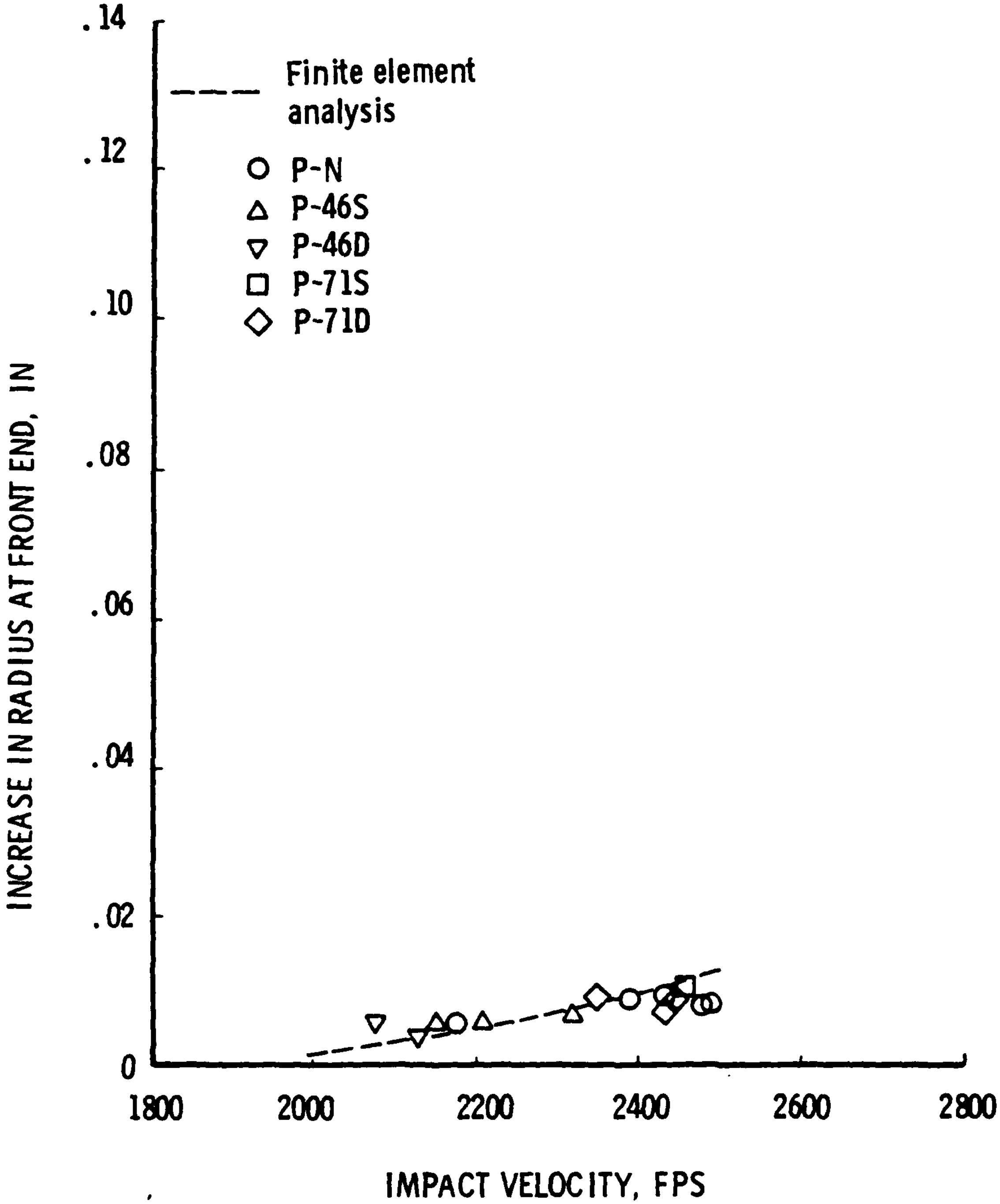


FIGURE 6. Increase in Radius at Front End Versus Impact Velocity for Test Projectiles Fired Against Thorite.

TABLE 3. Results of Projectile Firings Against Steel-Plate Targets.

Projec. type	Mass, gm	Impact velocity, fps	Description of projectile after test
P-N	20.07	2480	Cracks on front surface, bulge at cavity front
P-N	20.02	2650	Ditto
P-N	20.04	2825	Ditto
P-N	19.82	2995	Side of front end nearly broken off
P-N	20.12	3230	Cracks on front surface form circular plug
P-N	20.05	3590	Front end disintegrated and not recovered
P-46S	20.02	2570	Cracks on front surface, bulge at cavity front
P-46S	19.98	2835	Ditto
P-46S	19.72	2985	Circular pattern for cracks on front surface
P-46S	19.85	3275	Front end mashed on one side, target disk still attached
P-46S	19.98	...	Projectile jammed in gun barrel; only front portion struck target
P-46D	19.80	2545	Cracks on front surface; shape of cavity bulge shows effect of groove
P-46D	19.92	2640	Ditto
P-46D	19.61	2830	Side of front end mashed; circumferential fracture at groove
P-46D	19.92	2950	Ditto
P-46D	19.88	3230	Front end shattered on one side, target disk still attached; fracture at groove
P-71S	19.97	2505	Cracks on front surface, slight bulge at cavity front
P-71S	19.97	2650	Ditto
P-71S	20.02	2825	Ditto
P-71S	20.01	2980	Cracks on front surface form circle; bulge at cavity front, smaller bulge at groove
P-71S	19.85	3160	Longitudinal crack in side of front end, target disk still attached
P-71D	19.88	2495	Cracks on front surface, bulges at cavity front and groove
P-71D	19.85	2660	Ditto
P-71D	19.84	2840	Ditto
P-71D	19.96	2970	Cracks on front surface form circle; distinctive shape of groove bulge apparent
P-71D	20.05	3250	Front end shattered on one side, target disk still attached

bulge. The presence of a groove at the more rearward location produced a secondary bulge at this point. Those projectiles containing a deep groove at the cavity bulge location and fired at high velocities developed partial circumferential fractures at the bulge (Figure B-3, P-46D, 2830 fps, 2950 fps, and 3230 fps). For the other types of projectiles, however, increasing impact velocity resulted in increasing damage to the front end with no visible damage at either the primary or secondary bulge location. (Metallographic examination of cross-sectioned projectiles revealed the presence of tensile cracks at the roots of the grooves in projectiles fired against both Thorite and steel-plate targets. These appear to have been produced during unloading. The metallurgical aspects of projectile behavior will be discussed in a later report.)

CONCLUSIONS

The purpose of this study was to examine possible deleterious effects of shear-control grids on the survivability of impacting warheads. The single circumferential groove machined into the test projectiles was intended to represent the stress-raising capability of a shear-control grid in its vicinity. To the extent that this representation is valid, the results show that:

1. For warheads fired against concrete targets, the presence of a shear-control grid in the vicinity of the region of maximum bulging in the warhead case significantly weakens the warhead structurally. Moreover, the reduction in survival velocity increases with the depth of the groove. However, if the grid does not extend into the bulged region, no weakening occurs. Thus, a shear-control grid can be machined from slightly behind the bulge (half a projectile diameter in this study) to the rear of a warhead case without reducing survivability while, at the same time, maintaining a significant amount of fragmentation control.

2. For warheads fired against steel-plate targets, the situation is less clear. Damage to the projectiles fired against such targets occurred primarily at the front end, and a groove in the internal cavity, whether at the bulge or behind it, had little effect on structural survivability. Circumferential cracks did occur in some of the projectiles containing a deep groove at the bulge; however, damage to the front end was already extensive. It is likely that another projectile design with a thinner case wall might have fractured at the bulge at a lower velocity with little damage to the front end. In this case, the effects of groove placement and depth on survivability might have been similar to those found for concrete penetration.

Appendix A

PROCEDURE FOR MAKING THORITE TARGETS

It is essential that the Thorite targets used in small-scale projectile test firings be made in a consistent manner so that all targets have the same mechanical properties. The procedure used in making these targets so as to assure uniformity is described.

1. The targets are usually prepared in batches of 10 at one time. This number of targets can be prepared in about 1 hour and can be comfortably test-fired in half a day. Target preparation is usually done out-of-doors in the early morning. On exceptionally hot or cold days, it might be desirable to work inside to avoid temperature extremes.

2. The Thorite for each target is mixed in a circular plastic dishpan. The water required (1250 milliliters) is poured into the dishpan first. Then the dry Thorite (4300 milliliters) is added. The ingredients are worked with the hands (disposable vinyl gloves are worn for protection) until thoroughly blended and lump-free.

3. The mixture is then poured into a clean, empty 1-gallon paint can. The can is filled to just below the inner lip. The mixture is packed slightly in the can, using the hands. After filling, the can is held by the bail and bounced gently on a flat surface until the surface of the Thorite has smoothed out.

4. The newly filled can is placed for cooling in a tub of water with the water level slightly below the rim of the can. After the surface of the Thorite has set (about 5 minutes) water is poured into the can to fill it to the rim.

5. After 2 hours, all the cans are removed from the tub and stored indoors. The cans are kept covered with water for 24 hours after preparation. At the end of this time the water is poured off and the surface of the Thorite is allowed to dry out. The cans are used for test firing 1 week after preparation.

Appendix B

PHOTOGRAPHS OF PROJECTILES AFTER TEST

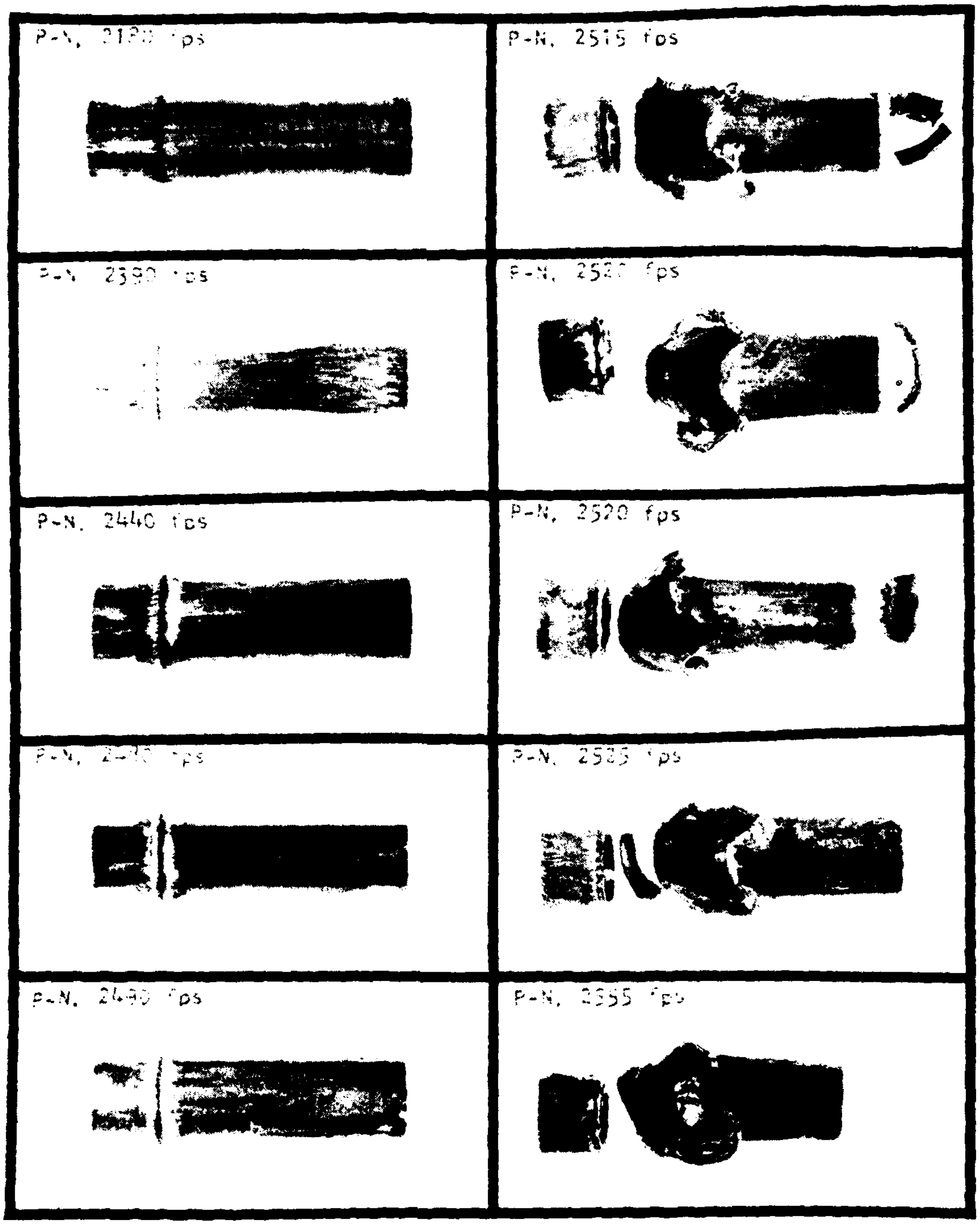


FIGURE B-1. Side Views of Projectiles Fired Against Thorite Targets.

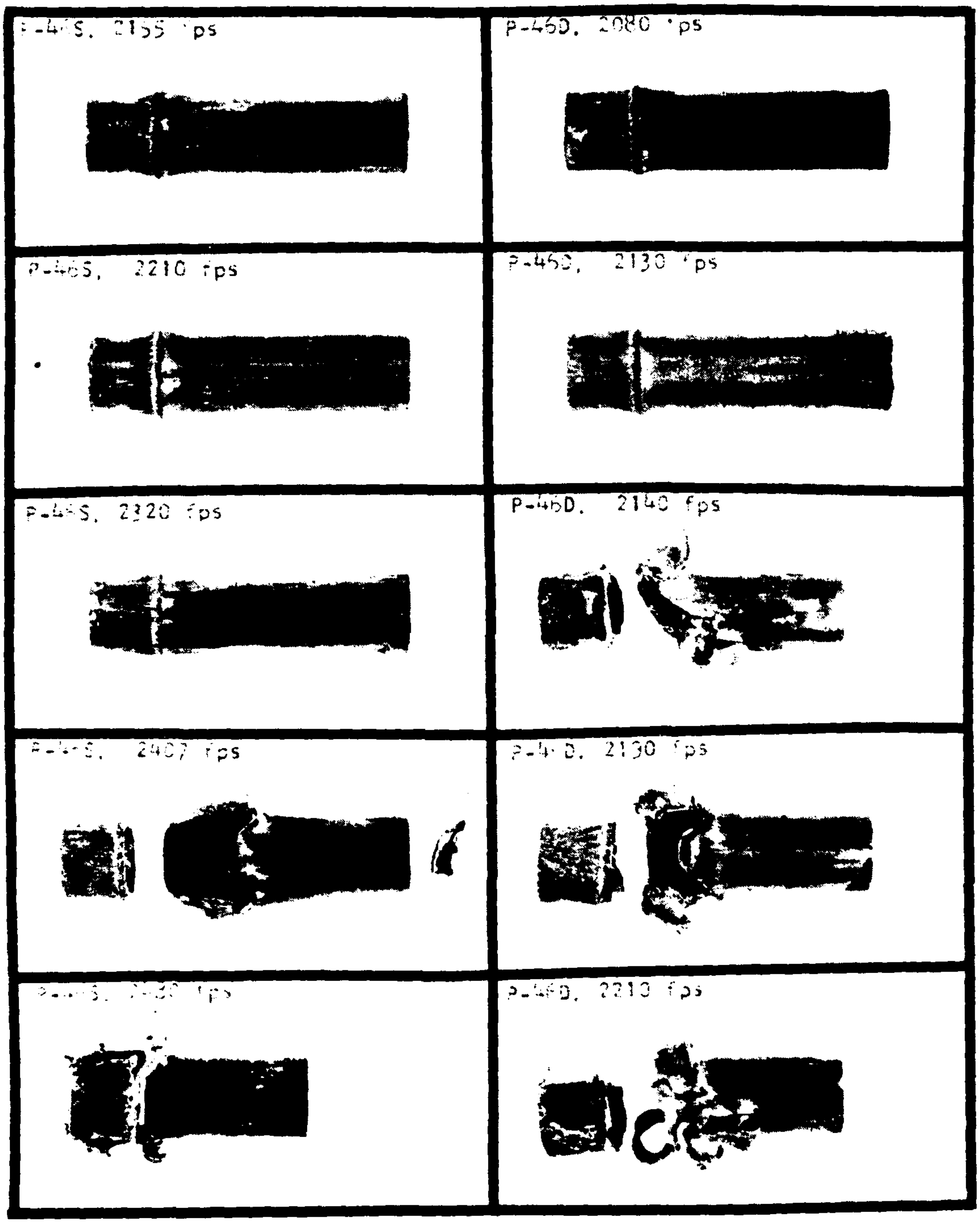


FIGURE B-1. (Contd.)
Side Views of Projectiles Fired Against Thorite Targets.

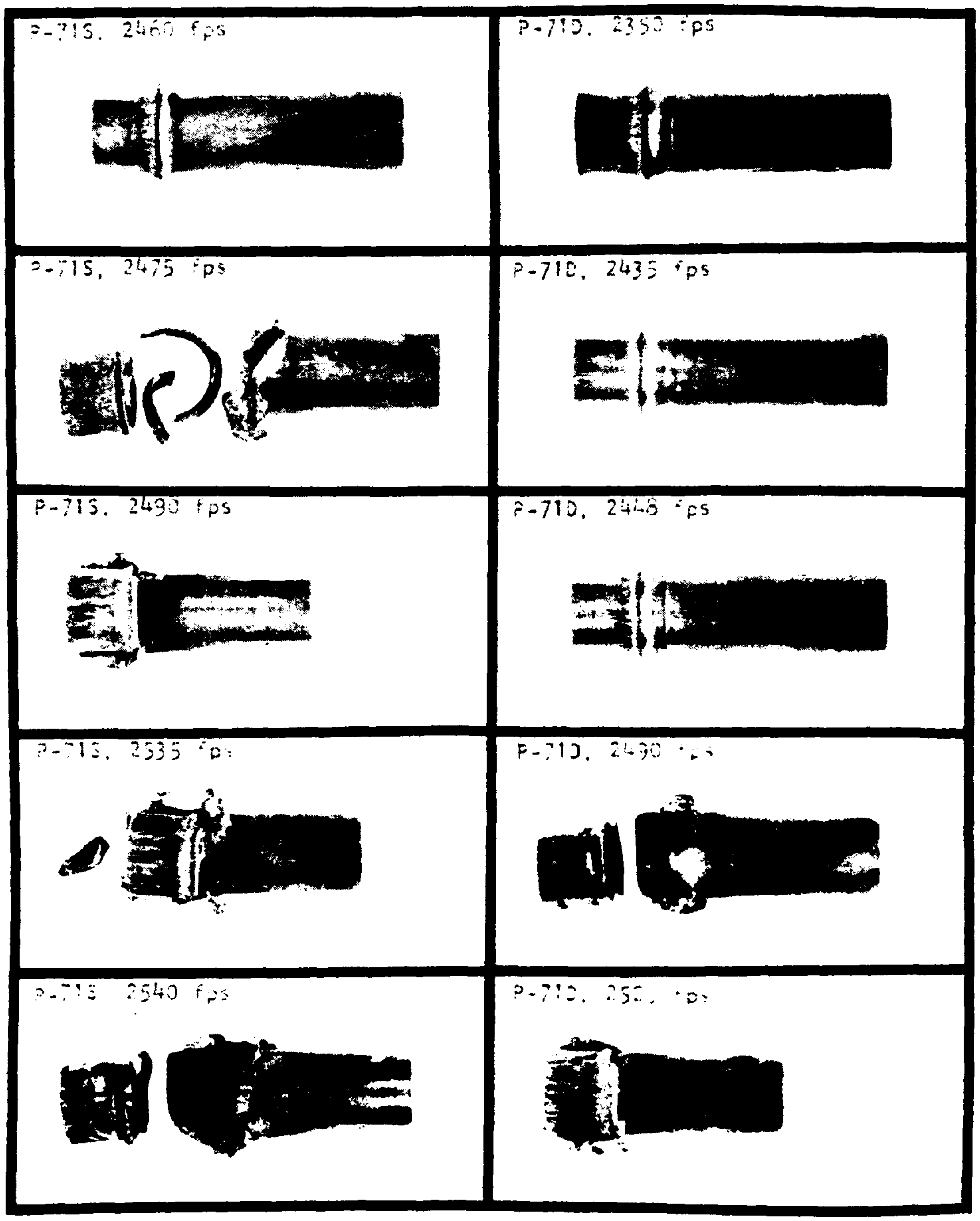


FIGURE B-1. (Contd.)
Side Views of Projectiles Fired Against Thorite Targets.

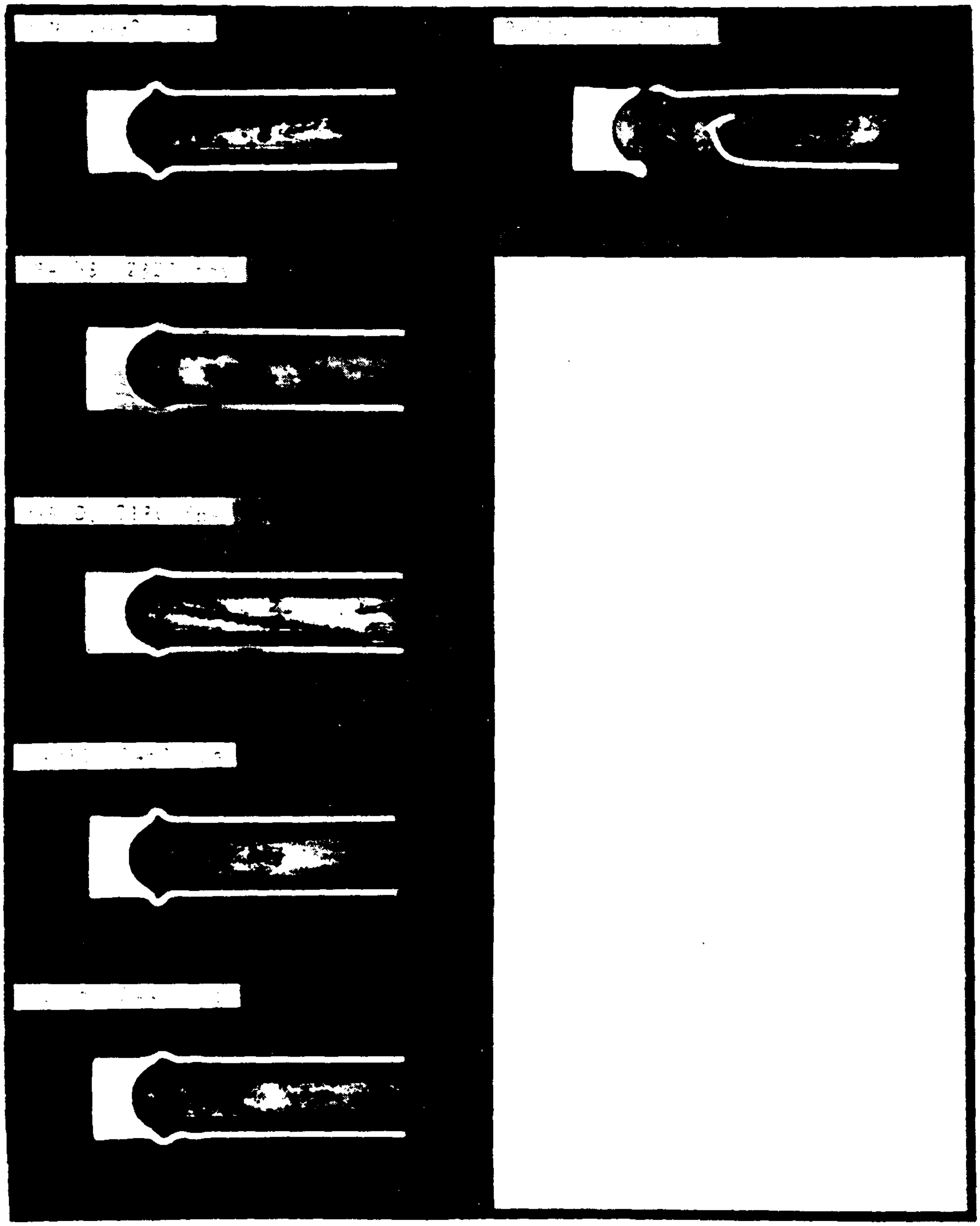


FIGURE B-2. Cross-Sectional Views of Selected Projectiles Fired Against Thorite Targets.

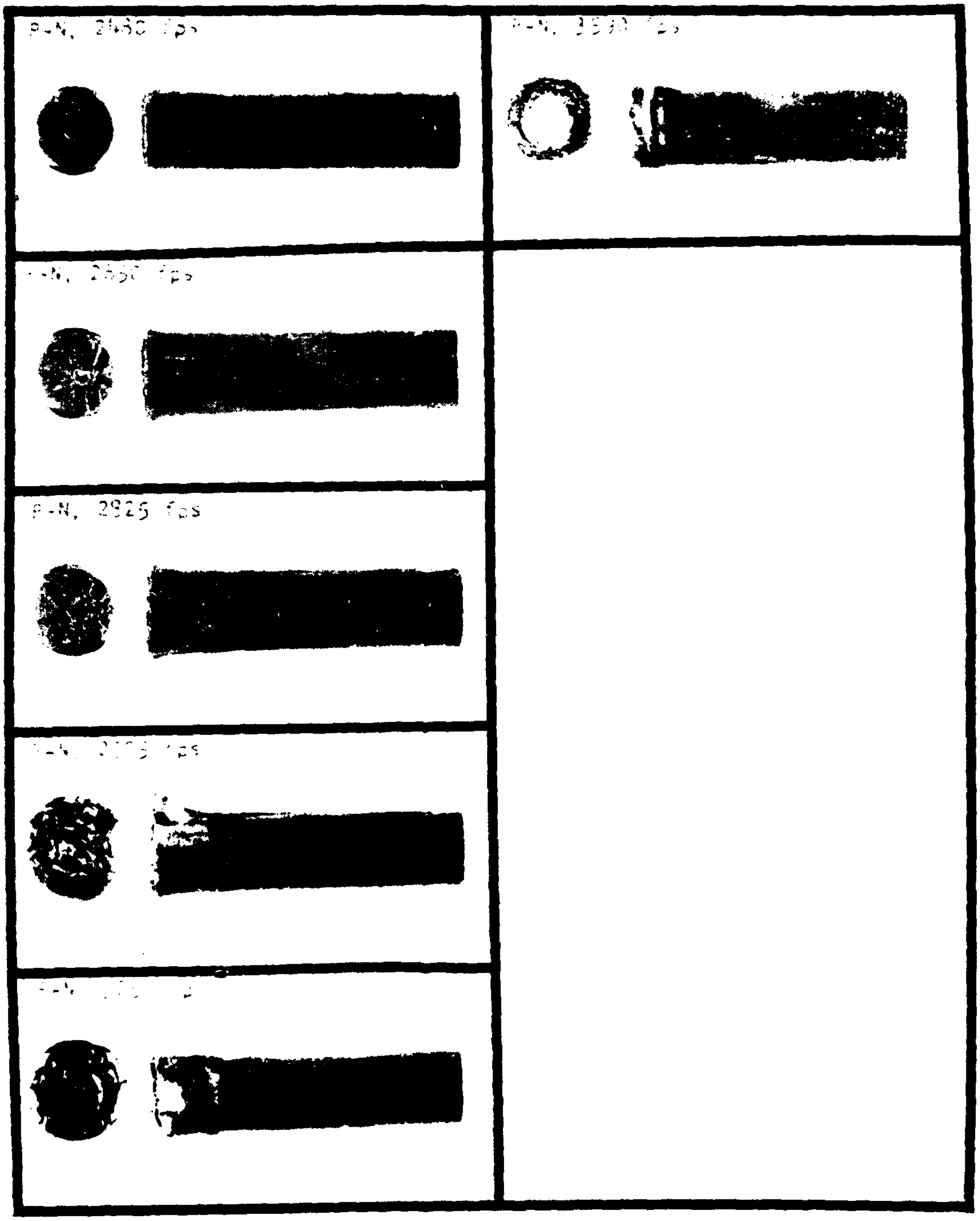


FIGURE B-3. Front and Side Views of Projectiles Fired Against Steel Plate Targets.

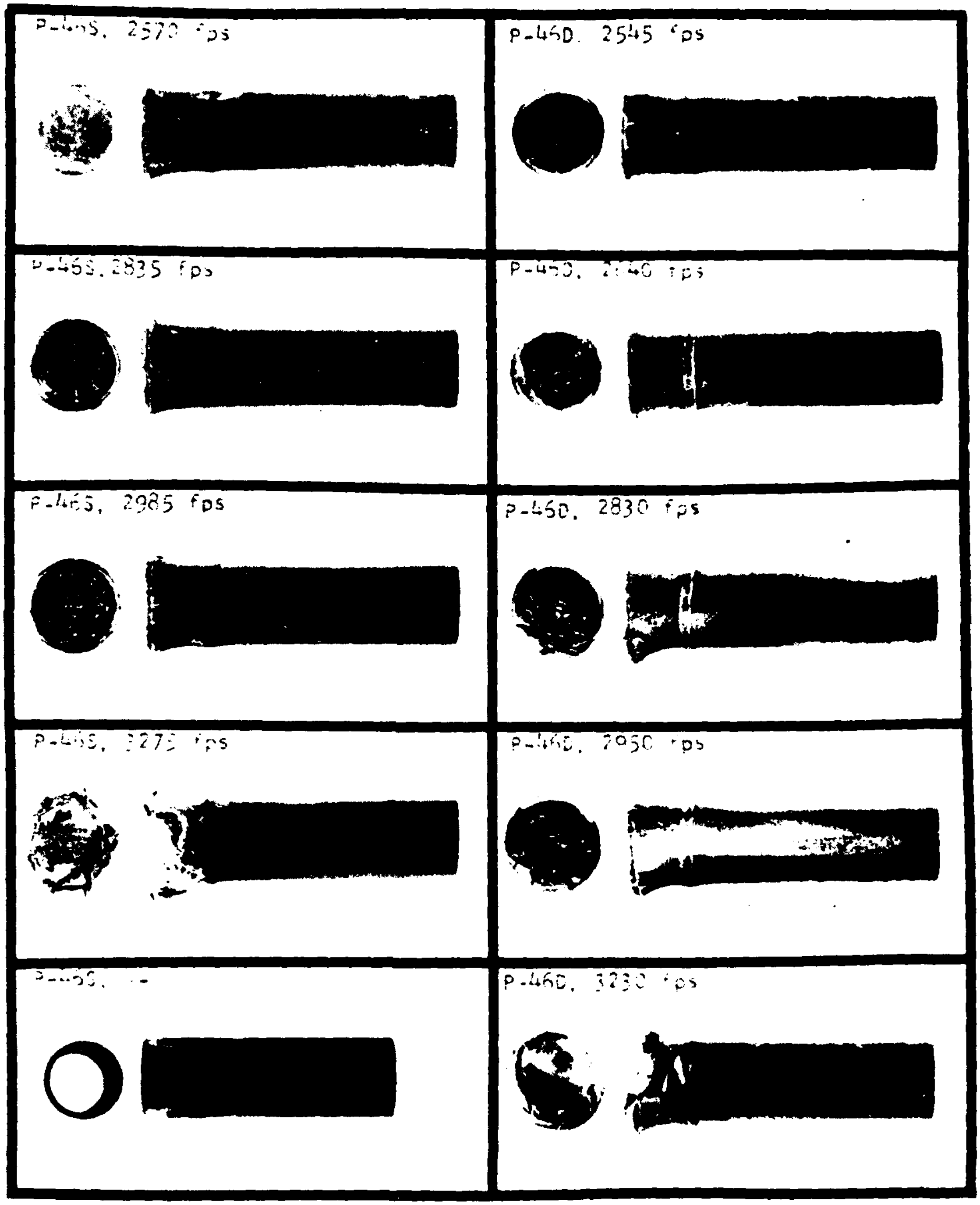


FIGURE B-3 (Contd.). Front and Side Views of Projectiles Fired Against Steel Plate Targets.

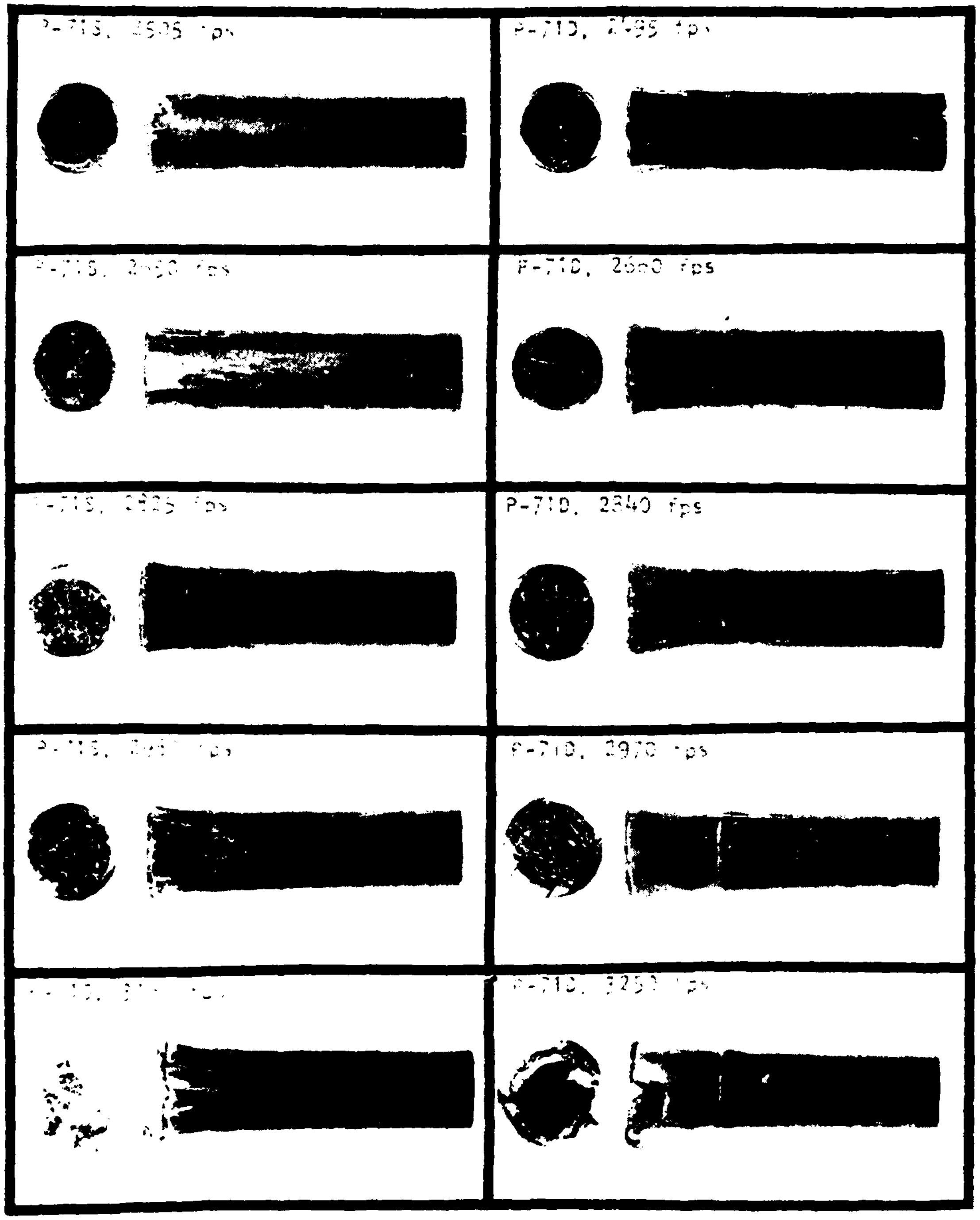


FIGURE B-3 (Contd.). Front and Side Views of Projectiles Fired Against Steel Plate Targets.

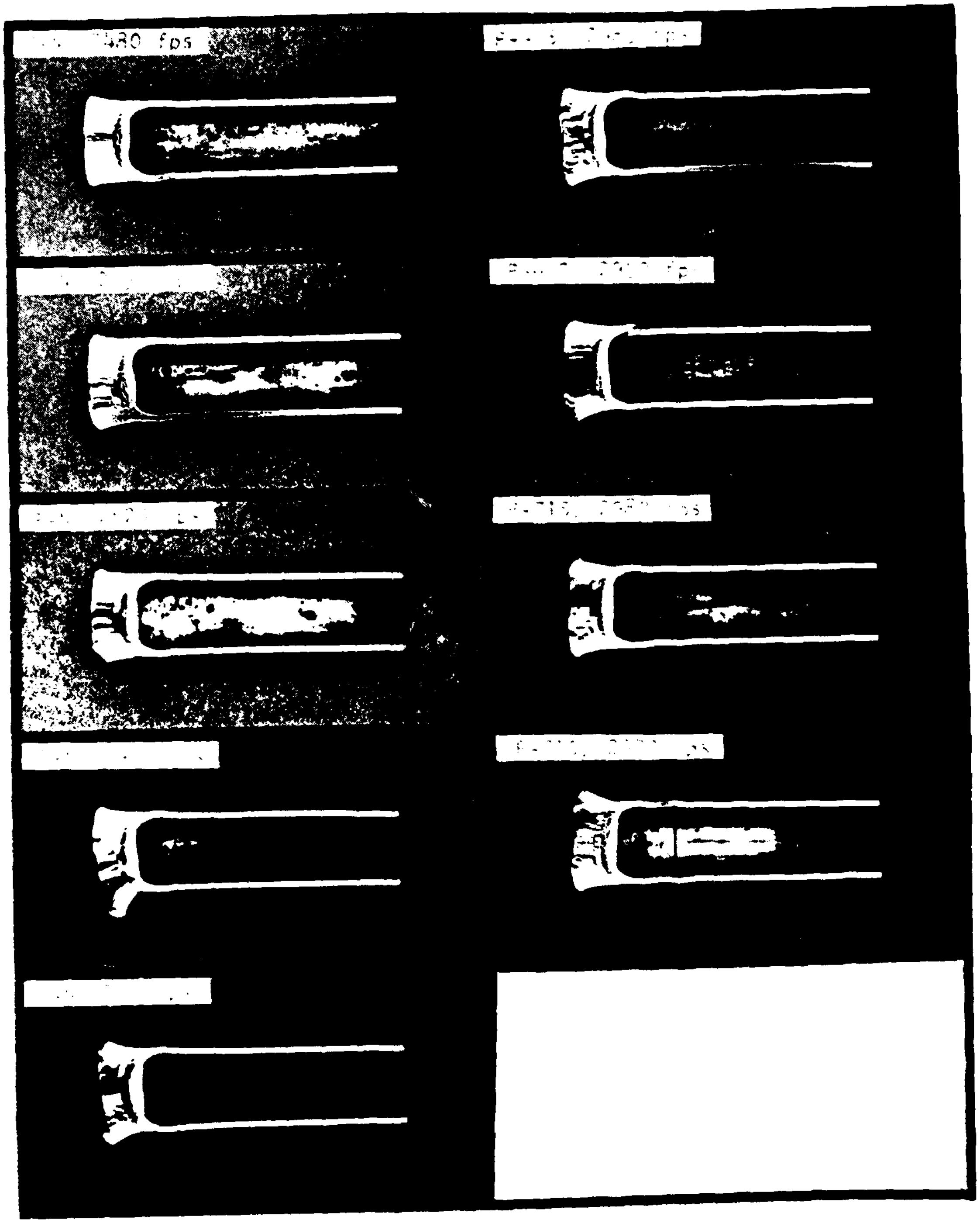


FIGURE B-4. Cross-Sectional Views of Selected Projectiles Fired Against Steel Plate Targets.

INITIAL DISTRIBUTION

1 Assistant Deputy Chief of Naval Material for Laboratory Management (MAT-08L)
10 Naval Air Systems Command
    AIR-00D4 (2)
    AIR-30212 (2)
    AIR-350 (1)
    AIR-350D (1)
    AIR-512 (1)
    AIR-533 (1)
    AIR-541 (2)
5 Chief of Naval Operations
    OP-03 (2)
    OP-05 (1)
    OP-098 (1)
    OP-55 (1)
2 Chief of Naval Material
    MAT-07 (1)
    MAT-08 (1)
7 Naval Sea Systems Command
    SEA-62R (5)
    SEA-99612 (2)
4 Chief of Naval Research, Arlington
    ONR-102 (1)
    ONR-461 (1)
    ONR-473 (1)
    ONR-474 (1)
1 Air Test and Evaluation Squadron 5
1 David Taylor Naval Ship Research and Development Center, Bethesda
1 Fleet Anti-Air Warfare Training Center, San Diego
1 Marine Air Base Squadron 32, Beaufort
1 Marine Corps Air Station, Beaufort
1 Naval Air Engineering Center, Lakehurst
1 Naval Air Force, Atlantic Fleet
2 Naval Air Force, Pacific Fleet
1 Naval Air Station, North Island
2 Naval Air Test Center (CT-176), Patuxent River (Aeronautical Publications Library)
1 Naval Avionics Center, Indianapolis (Technical Library)
1 Naval Explosive Ordnance Disposal Facility, Indian Head
1 Naval Ocean Systems Center, San Diego (Code 1311)
1 Naval Ordnance Station, Indian Head (Technical Library)

1 Naval Postgraduate School, Monterey
5 Naval Surface Weapons Center Detachment, White Oak Laboratory, Silver Spring
    WR-13, R. Liddiard (1)
    J. Erkman (1)
    Dr. S. Jacobs (1)
    Guided Missile Warhead Section (1)
    Technical Library (1)
1 Office of Naval Research Branch Office, Chicago
1 Office of Naval Research Branch Office, Pasadena
1 Operational Test and Evaluation Force, Norfolk
1 Pacific Missile Test Center, Point Mugu (Technical Library)
1 Army Armament Materiel Readiness Command, Rock Island (DRSAR-LEP-L, Technical Library)
4 Army Armament Research & Development Command, Dover
    DRDAR-LCU-SS, J. Pentel (1)
    Technical Library (3)
1 Aberdeen Proving Ground (Development and Proof Services)
3 Army Ballistic Research Laboratories, Aberdeen Proving Ground
    DRDAR-SEI-B (1)
    DRDAR-T, Detonation Branch (1)
    DRDAR-TSB-S (STINFO) (1)
1 Army Material Systems Analysis Agency, Aberdeen Proving Ground (J. Sperrazza)
1 Army Research Office, Durham
1 Harry Diamond Laboratories (Technical Library)
1 Radford Army Ammunition Plant
1 Redstone Arsenal (Rocket Development Laboratory, Test and Evaluation Branch)
1 Rock Island Arsenal
1 White Sands Missile Range (STEWS-AD-L)
1 Yuma Proving Grounds (STEYT-GTE, M&W Branch)
1 Tactical Air Command, Langley Air Force Base (TPL-RQD-M)
1 Air University Library, Maxwell Air Force Base
3 Armament Development & Test Center, Eglin Air Force Base
2 57th Fighter Weapons Wing, Nellis Air Force Base
    FWW/DTE (1)
    FWW/DTO (1)
1 554th Combat Support Group, Nellis Air Force Base (OT)
1 Tactical Fighter Weapons Center, Nellis Air Force Base (CC/CV)
12 Defense Technical Information Center
1 Defense Nuclear Agency (Shock Physics Directorate)
1 Weapons Systems Evaluation Group
1 Lewis Research Center
2 Allegany Ballistics Laboratory, Cumberland, MD
2 Applied Physics Laboratory, JHU, Laurel, MD (Document Library)
1 Arthur D. Little, Inc., Cambridge, MA (W. H. Varley)
2 Chemical Propulsion Information Agency, Applied Physics Laboratory, Laurel, MD

1 IIT Research Institute, Chicago, IL (Document Librarian for Department M)
1 Jet Propulsion Laboratory, CIT, Pasadena, CA (Technical Library)
1 Los Alamos Scientific Laboratory, Los Alamos, NM (Reports Library)
1 Princeton University, Forrestal Campus Library, Princeton, NJ
1 Stanford Research Institute, Poulter Laboratories, Menlo Park, CA
1 The Rand Corporation, Santa Monica, CA (Technical Library)
1 University of California, Lawrence Livermore Laboratory, Livermore, CA
1 University of Denver, Denver Research Institute, Denver, CO
1 University of South Florida, Tampa, FL (Dept. of Structures, Materials, and Fluids, W. C. Carpenter)